

III. Evaluating Properties

F. Property Tables

1. What's in the tables and why

- specific volumes, v (m^3/kg) (as v , v_i , v_f , v_g)
- pressure, P (kPa)
- temperature, T (C)
- internal energy, u (kJ/kg) (as u , u_i , u_f , u_g , u_{ig} , u_{fg})
- enthalpy, $h = u + Pv$ (kJ/kg) (as h , h_i , h_f , h_g , h_{ig} , h_{fg})
- entropy, s (kJ/kg K) (as s , s_i , s_f , s_g , s_{ig} , s_{fg})

i = saturated solid (ice)
 f = saturated liquid (fluid)
 g = saturated vapor (gas)
 ig = value for g - value for i
 fg = value for g - value for f

These subscripts are only used in two-phase regions.

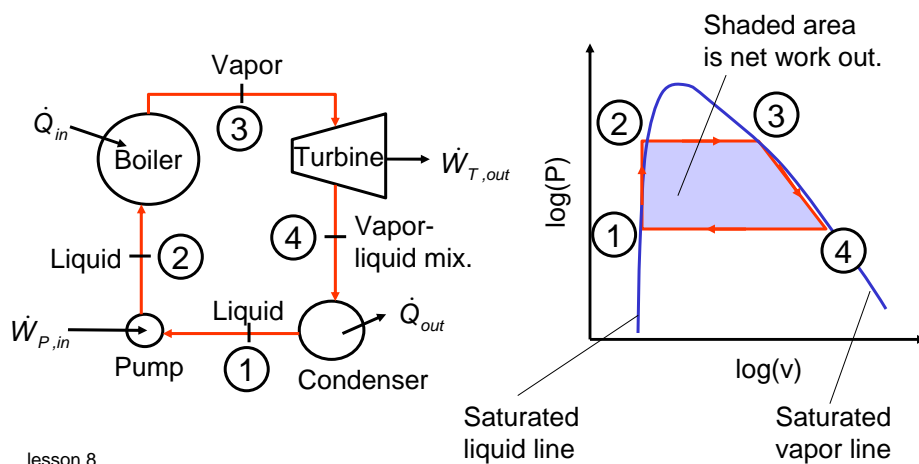
The functional relationships between the properties are complex and are therefore tabulated for convenience.

lesson 8

III. Evaluating Properties

1. What's in the tables and why

Simple, ideal vapor power cycle (Rankine cycle, Ch. 10, p. 553).



lesson 8

III. Evaluating Properties

2. Saturated liquid and vapor states (saturation dome)

- Table A-4, properties as a function of T_{sat}
- Table A-5, properties as a function of P_{sat}
- When both the liquid and vapor phases are present, define the quality, x , as the weight fraction of vapor.
- Use the quality to calculate the properties of the mixture.

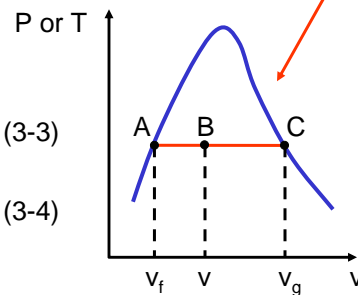
Quality is a function of the horizontal distances on P-v and T-v diagrams.

$$m_{\text{total}} = m_{\text{vapor}} + m_{\text{liq}}$$

$$x = \frac{m_{\text{vapor}}}{m_{\text{total}}} = \frac{\overline{AB}}{\overline{AC}} = \frac{v - v_f}{v_{fg}} \quad (3-3)$$

$$v = (1 - x)v_f + xv_g = v_f + xv_{fg} \quad (3-4)$$

$$v_{fg} = v_g - v_f$$



lesson 8

III. Evaluating Properties

e. Example 1 - Hard hike.

During a hard hike your body loses about 1.0 liter/hour of water to evaporation. How much cooling does this provide as measured in kcal/h and W?

Assumption: Evaluate all properties at the temperature of the skin.

Data: Temperature of skin is roughly 35 C.

Specific volume of water is $v_f = 0.001006 \text{ m}^3/\text{kg}$ (Table A-4)

Heat of vaporization is $h_{fg} = h_g - h_f = 2418.6 \text{ kJ/kg}$ (Table A-4)

$1 \text{ kcal} = 1 \text{ Cal} = 4.1868 \text{ kJ}$

Calculation:

$$\dot{Q}_{\text{evap}} = \dot{m}_{\text{vapor}} h_{fg} \left[\text{where } \dot{m}_{\text{vapor}} = \frac{dm_{\text{vapor}}}{dt} \left(\frac{\text{kg}}{\text{s}} \right) \right]$$

$$\dot{Q}_{\text{evap}} = 1.0 \frac{\text{L}}{\text{h}} \frac{1 \text{ h}}{(3600 \text{ s})} \frac{1 \text{ m}^3}{10^3 \text{ L}} \frac{1 \text{ kg}}{(0.001006 \text{ m}^3)} 2418.6 \frac{\text{kJ}}{\text{kg}}$$

$$\dot{Q}_{\text{evap}} = 0.668 \text{ kJ/s} = 668 \text{ W}$$

$$\dot{Q}_{\text{evap}} = 0.668 \text{ kJ/s} \frac{1 \text{ kcal}}{4.1868 \text{ kJ}} \frac{3600 \text{ s}}{1 \text{ h}} = 574 \frac{\text{kcal}}{\text{h}}$$

lesson 8

III. Evaluating Properties

e. Example 1 – Hard hike.

The amount of energy required to vaporize 1 kg of water, **at constant pressure**, is the **enthalpy of vaporization**, h_{fg} (kJ/kg). At 1 atm (100°C), $h_{fg} = 2257$ kJ/kg.

lesson 8

III. Evaluating Properties

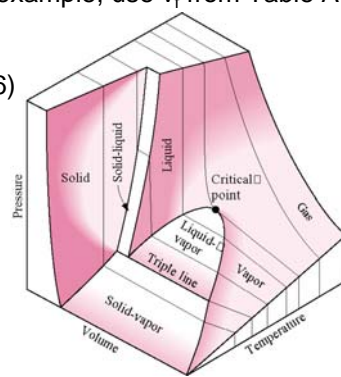
3. **Superheated vapor** state (Table A-6)

4. **Compressed liquid** state

a. Table A-7 for high pressures (≥ 5 MPa)

b. At moderate pressures, compressed liquid properties can be approximated by using the desired property at the saturated liquid state at the given temperature. For example, use v_f from Table A-4 at $T_{sat} = T$.

(Cengel and Boles Fig. 3-26)



From the PvT surface we see that in the compressed liquid region, extreme pressures are needed to change v . Hence, at moderate p , we can use u_f and v_f in saturated liquid region to approximate values in compressed liquid region.

lesson 8

III. Evaluating Properties

c. Example 2. Finding properties with tables.

Given: $P = 5 \text{ atm}$, $T = 25^\circ\text{C}$

Find: phase description, v , and u

Approach: **always start with the saturation tables (A-4, 5)**

Solution:

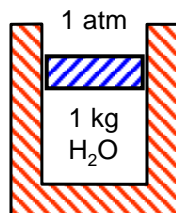
From Table A-4 (sat. water - T table) at $T = 25^\circ\text{C}$, $P_{\text{sat}} = 3.169 \text{ kPa}$. So we know we are in **compressed liquid region**. If we try to use Table A-7 (comp. liq. water), we notice that we are outside the range of pressure values. So we go back to Table A-4 at $T = 25^\circ\text{C}$ and read $v \approx v_f = 0.001003 \text{ m}^3/\text{kg}$ and $u \approx u_f = 104.88 \text{ kJ/kg}$.

lesson 8

III. Evaluating Properties

d. Example 3. Cooling of piston-cylinder device.

A cylinder containing 1.00 kg of water is fitted with a frictionless, weightless piston. The initial temperature of the water is 102 C. The constant air pressure outside the cylinder is 1 atm = 101.325 kPa. The bottom part of the cylinder is placed in a constant temperature bath at 98 C and allowed to come to equilibrium. When the whole system is at 98 C, how much heat has flowed out?



1.00 kg H_2O (system)
 $T_1 = 102 \text{ C}$
 $T_2 = 98 \text{ C}$
 $P_1 = P_2 = 101.325 \text{ kPa}$

lesson 8

III. Evaluating Properties

d. Example 3. Cooling of piston-cylinder device.

What is special about this process? Because the piston is frictionless and weightless, the pressure of the system is constant and equal to the atmospheric pressure: $P_1 = P_2$. Because the initial temperature is above the saturation temperature at 1 atm, the water must initially be superheated vapor. Because the final temperature is below the saturation temperature at 1 atm, the water must finally be a compressed liquid.

Assume that the processes can be modeled as a quasi-equilibrium process. **Assume** that changes in the kinetic and potential energy are negligible.

Apply the conservation equations and solve for unknown Q_{out} .

lesson 8

III. Evaluating Properties

d. Example 3. Cooling of piston-cylinder device.

From the first law, neglecting changes in KE and PE,

$$\Delta U = Q_{in} - W_{out} = -Q_{out} - W_{out} = -Q_{out} - P\Delta V$$

Rearrange and define **the enthalpy**: $\Delta H = \Delta U + \Delta(PV)$ (3-2)

$$Q_{out} = -(\Delta U + P\Delta V) = -\Delta H = -m(h_2 - h_1) = h_1 - h_2$$

From Table A-4, $h_2 = 410.61$ kJ/kg (comp. liq., use sat. liquid prop.)

From Table A-6, $h_1 = 2679.18$ kJ/kg (superheated vap.)

Finally,

$$Q_{out} = 2679.18 - 410.61 = 2270 \text{ kJ}$$

lesson 8

III. Evaluating Properties

5. Saturated ice-water vapor (Table A-8)
6. Reference values for water
 - a. Triple point of water is 0.01°C
 - b. u_f and s_f are **defined** to be zero at the triple point
7. Selection of property data

Energy is a relative quantity. We need the change in energy.

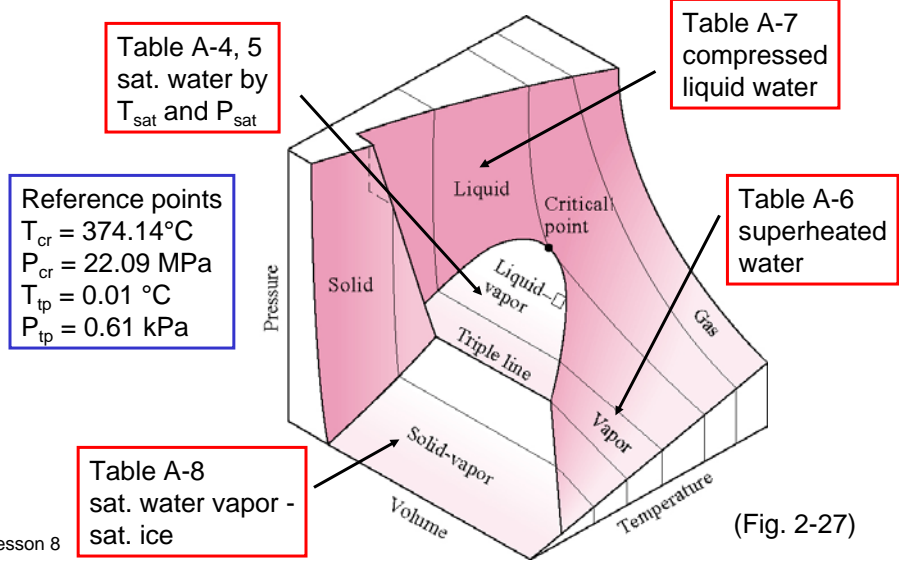
- a. Given a set of property data that specify the state, it is frequently difficult to know which table to use.
- b. **RULE OF THUMB: start with the saturation tables.**
- c. Example

Given: $P = 0.3 \text{ MPa}$, $v = 0.651 \text{ m}^3/\text{kg}$
 Find: T (°C), quality, phase description
 Solution:
 From Table A-5 (sat. pressure table) at $P = 0.3 \text{ MPa}$,
 $v_f = 0.001073$ and $v_g = 0.6058 \text{ m}^3/\text{kg}$. Because $v > v_g$, we conclude that the water is superheated. Interpolating in Table A-6 (superheated water) at $P = 0.3 \text{ MPa}$, the given specific volume corresponds to $T = 160^\circ\text{C}$.

lesson 8

III. Evaluating Properties

8. Overview of the tables for water



lesson 8